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CONTRACT NAS 8-35817

STUDY OF HIGH PERFORMANCE ALLOY ELECTROFORMING
SIXTEENTH MONTHLY TECHNICAL PROGRESS NARRATIVE

APRIL 1, 1985 TO APRIL 26, 1985

ELECTROFORMING OPERATIONS DEPARTMENT

BELL AEROSPACE TEXTRON

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STUDY OF HIGH PERFORMANCE ALLOY ELECTROFORMING

ABSTRACT

Using the two nickel-manganese alloy electroforming baths of near identical compositions, panels were electroformed under the same deposition parameters of current density, bath temperature, pH, and pulse plating conditions of duty cycle and frequency. By changing the electrolyte agitation conditions, significant effects on mechanical properties were noted. Since electrolyte agitation conditions on the typical flat panels studied to date will not be identical to those existing on a complex curved shape such as the SSME combustion chamber simulation, it is most important that these effects be evaluated prior to Phase B studies. The subscale chamber has been fabricated and shield support tooling is being made. Electroforming of optimized alloy test bars is being deferred until the electrolyte agitation effects are more fully appraised.

I. INTRODUCTION

The purpose of this work is to develop and demonstrate a system for electroforming materials with improved strength and high-temperature properties. The Space Shuttle Main Engine employs a main combustion chamber (MCC) where final combustion of propellant at high temperature and pressure takes place. This critical component must be structurally supported by a nickel-base alloy jacket. Producing this jacket from formed wrought metal segments requires numerous weldments which alter the mechanical properties of the base metal through heat affected zones. This requires thickening the alloy where joints are to be made to meet the structural requirements of the shroud. The use of electroformable alloys with great strength would have the potential for simplifying fabrication procedures for structural jackets and reducing overall weight by removing weldments. Such an electroformable alloy might also afford a possible use in advanced engines where light weight and good strength at high temperatures are necessary.

II. TECHNICAL PROGRESS SUMMARY

A. Task I - Literature Survey (Phase A) - Previously completed.

B. Task II - Alloy Characterization and Optimization (Phase A)

Summarizing the effects of various electrolyte and pulse plating parameters on mechanical properties of nickel-manganese electroformed alloys:

1. Increasing the manganese content of the electrolyte results in an increased manganese content in the alloy. This results in increased mechanical strength and a decrease in ductility (which can often be restored by a moderate heat treatment). Manganese contents in deposits exceeding 2500 ppm by weight require more prolonged or severe heat treatments to restore ductility while 5000 ppm, or more, manganese in the alloy usually results in a brittle and highly tensile stressed "as deposited" metal. The form in which the manganese is codeposited with nickel (i.e. - whether in the composition Ni_3Mn or NiMn) may have an important influence on stress and mechanical properties.

2. Increasing the current density in the conventional dc plating mode or the average current density in the pulse plating mode increases manganese concentration in the alloy in a logarithmic manner. In the pulsed current mode and for a constant average current density, it appears that increasing the peak current density also increases manganese content and mechanical strength - provided the pulse off time is sufficiently long. Pulse off times of 10 to 30 milliseconds appear to produce better mechanical properties than lesser times. This is probably due to the longer diffusion time for manganese to reach equilibrium concentrations in the diffusion layer at the cathode. Since this may also be strongly influenced by electrolyte agitation which leads to thinner diffusion layers, we will discuss this subsequently.

3. Electrolyte pH - at least in the normal range of 3.8 to 4.3 - has not been noted to have a significant effect on alloy manganese concentration or mechanical properties. Hydrogen ion may play a part in electron transfer in the reduction of nickel and manganese (or coordinated nickel-manganese ions which might resemble coordination complex ions). Since hydrogen is reduced, or "plates" at the cathode, the diffusion layer tends to become less acidic. This is easily offset by electrolyte agitation which thins out the diffusion layer and allows quicker hydrogen ion diffusion to restore the proper pH. Pulse plating permits the same hydrogen ion diffusion to occur during the pulse off time.

4. Bath temperature increase results in a significant decrease in alloy manganese concentration. Ion migration in the diffusion layer should be easier as the layer temperature increases. This would indicate that nickel ion diffusion is enhanced by increases in temperature while manganese ion diffusion is not - or, if nickel-manganese ion coordinations exist, the relative mobility of such complexes is not improved by higher bath temperatures.

5. Deposition voltage is directly related to manganese content in the alloy. High voltages lead to high manganese concentrations in deposits. Since increased current densities are accompanied by increased overvoltages, it is to be expected that this would occur.

6. Pulse frequencies (particularly the length of off time) appear to affect the codeposition of manganese with nickel. As was mentioned in the report of the previous month, high pulse frequencies with off times as short as 2 milliseconds resulted in less manganese (and lower mechanical strength) than lower frequencies with off times in the 20 millisecond range. In each case the pulse duty cycle was the same (50%). There seems to be a practical limitation on use of longer off times since sufficient chemical equilibrium is restored if good bath agitation exists to keep the diffusion layer thin.

The above discussion has in many cases pointed to electrolyte agitation and the resulting "thinning" of the diffusion layer to permit better diffusion of manganese ions for codeposition with nickel. The serious effects of agitation on alloy composition and mechanical properties became clearly evident in the April work on flat panels. In this effort we were endeavoring to duplicate, or improve upon, the mechanical properties of Panel NM-25 where ultimate strength exceeded 175 ksi (even after heat treating at 427°C for four hours) and elongation was at least 10 percent. The panel fabrication matrix included use of several pulse duty cycles in the 25% to 60% range and lower frequencies of 25 to 50 Hz. Long pulse off times were being investigated since the off time for Panel NM-25 was 20 milliseconds.

When the duplicate nickel-manganese alloy electroforming facility was established, all spray systems were overhauled - including that in the first facility. Single "Fulljet" solid square spray nozzles were installed in each pumped electrolyte outlet perpendicular to the plane of the panel being electroformed. These sprays were 3/8HH24WSQ with a rated flow of 1.8 GPM at 5 psig and 2.4 GPM at 10 psig. Nozzle-to-electroform panel distance was 5 inches. Panels electroformed under this electrolyte spray condition are denoted by the word "Single" under the pulse plating information opposite "Sprays" on the attached tables of test data. A rearrangement of sprays was made whereby two "Fulljet" solid square spray nozzles pumped electrolyte on each panel being deposited. This permitted a higher volume electrolyte flow but a lower pressure. Such agitation conditions are described as "Double" under the pulse plating information for sprays on the attached data sheets. Any reference to "Single Square" means the same as "Single." All spray nozzles were obtained from Spray Systems Company, Wheaton, Illinois.

Data for Samples NMR-6A, -6B, and -6C afford an interesting comparison of spray effects on mechanical properties. Panel NMR-6A exhibited high yield and ultimate strengths using the "Single" spray set-up. Using double sprays of the same nozzle ratings and distance from the sample surface, a significant decrease in ultimate and yield strengths was observed. Most surprising is the fact that alloy analyses for Panel NMR-6B (using the double spray) was about the same as for Panel NMR-6A. For Panel NMR-6C, we moved the double spray from about 5 inches from the panel face to about 3.5 inches from the face. This maintained a high volume electrolyte turn-over at the panel face while increasing turbulence. Tests showed that ultimate and yield strengths were increased, and the manganese content was increased very significantly over that of Panel NMR-6A and Panel NMR-6B.

We interpreted this data to mean that the volume of electrolyte turn-over at the cathode face is not as critical as the shearing force of the spray at the cathode diffusion layer. The fact that Panels NMR-6A and B exhibited similar manganese contents and greatly differing mechanical properties can be accepted as compatible with the postulation that strong spray shearing action promotes a thinner diffusion layer and promotes codeposition of NiMn crystallographical cells while low shearing force favors Ni_3Mn cell formation. We have previously proposed that strengthening of nickel-manganese alloy is due to NiMn cells which are face-centered tetragonal and stable to fairly high temperatures. The mechanism whereby cathode surface turbulence controls the combinations in which nickel and manganese codeposition is not well understood.

Fabricated, or presently in electroforming, are panels representing the use of open pipe nipples for sprays, single solid square sprays mounted close to the cathode surface, and "Veejet" flat spray nozzles mounted close to the cathode surface. Results of tests for these panels should complete the parameters required to produce round test bars for optimum mechanical properties. We expect the "Veejet" nozzles to produce alloy with test results resembling those of Panel NM-25 (the best combination of mechanical strength and ductility thus far achieved).

In attached Tables I - V, it should be noted that mechanical testing was confined to the "as deposited" and heat treated at 650°F (343°C) conditions. Other heat treatments and testing at elevated temperatures was not performed in the interests of time and funding. Those samples showing best mechanical properties as electroformed will be submitted to a wide range of heat treatments and testing at MCC service temperatures. Tables I - V should be regarded as raw data to be expanded as appropriate.

TABLE I - ELECTROLYTE SPRAY EFFECTS EVALUATION

NASA CONTRACT NAS 8-35817 PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS

| Sample Number | Fabrication Data | Pulse Plating Information | Plating Bath Analytical Data | Deposited Alloy Data | Strip No. | Heat Treatment | Test Temp (°F) | Mechanical Properties (psi) | | |
|---------------|------------------|---------------------------|------------------------------|----------------------|-----------|----------------|----------------|-----------------------------|---------|-------------------------|
| | | | | | | | | Ultimate | Yield | Elong. (%) 1 in 2 in |
| NMR-5A | Start 03-14 | Duty Cycle 50% | Ni Metal 77.32 g/l | Panels 2 Each | 5A1A | None | Ambient | 185,820 | 143,285 | 7.8 5.7 |
| | Finish 03-15 | Pulse On 20.0 Msec | Mn Metal 4.6 g/l | Size 4.38"x 8.12" | B | 650°F(24 Hr) | Ambient | 188,880 | 164,375 | 9.3 4.9 |
| | Tank No. E01 | Pulse Off 20.0 Msec | Boric Acid 30.55 g/l | Mn Comp. 3205 ppm | C | | | | | |
| | Amp Hrs. 720 | Peak C.D. 50.60 ASF | Acidity(pH) 3.90 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.2°C | Flatness Fair | 5A2A | | | | | |
| NMR-5B | Start | Avg. Volts 4.70 | | Thickness .067 in | B | | | | | |
| | Finish | Sprays Single | | to .067 in. | C | | | | | |
| | Tank No. | | | | D | | | | | |
| | Amp Hrs. | | | | | | | | | |
| | | | | | | | | | | |
| NMR-5C | Start | Duty Cycle 50% | Ni Metal g/l | Panels 2 Each | 5C1A | None | Ambient | 191,715 | 148,570 | 8.0 5.8 |
| | Finish | Pulse On 20.0 Msec | Mn Metal g/l | Size 4.38"x 8.12" | B | 650°F(24 Hr) | Ambient | 192,795 | 161,385 | 5.2 3.3 |
| | Tank No. | Pulse Off 20.0 Msec | Boric Acid g/l | Mn Comp. ppm | C | | | | | |
| | Amp Hrs. | Peak C.D. 50.60 ASF | Acidity(pH) 4.01 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.4°C | Flatness Fair | 5C2A | | | | | |
| NMR-6A | Start 03-16 | Duty Cycle 50% | Ni Metal 75.85 g/l | Panels 2 Each | 6A1A | None | Ambient | 135,750 | 110,530 | 11.0 6.8 |
| | Finish 03-19 | Pulse On 12.0 Msec | Mn Metal 4.5 g/l | Size 4.38"x 8.12" | B | 650°F(24 Hr) | Ambient | 135,315 | 119,635 | 9.8 4.7 |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 30.55 g/l | Mn Comp. 2541 ppm | C | | | | | |
| | Amp Hrs. 720 | Peak C.D. 50.60 ASF | Acidity(pH) 4.01 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.4°C | Flatness Fair | 6A2A | | | | | |
| NMR-6B | Start 03-21 | Duty Cycle 50% | Ni Metal 75.51 g/l | Panels 2 Each | 6B1A | None | Ambient | 182,560 | 148,610 | 7.3 4.0 |
| | Finish 03-24 | Pulse On 12.0 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | B | 650°F(24 Hr) | Ambient | 180,605 | 140,885 | 8.7 5.5 |
| | Tank No. E02 | Pulse Off 12.0 Msec | Boric Acid 31.70 g/l | Mn Comp. 2443 ppm | C | | | 154,085 | 143,734 | 7.0 3.5 |
| | Amp Hrs. 720 | Peak C.D. 50.60 ASF | Acidity(pH) 4.00 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.7°C | Flatness Fair | 6B2A | | | | | |
| NMR-6C | Start 04-17 | Duty Cycle 50% | Ni Metal 76.87 g/l | Panels 2 Each | 6C1A | None | Ambient | 182,560 | 148,610 | 7.3 4.0 |
| | Finish 04-19 | Pulse On 12.0 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | B | 650°F(24 Hr) | Ambient | 180,605 | 140,885 | 8.7 5.5 |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 31.70 g/l | Mn Comp. 2443 ppm | C | | | 154,085 | 143,734 | 7.0 3.5 |
| | Amp Hrs. 700 | Peak C.D. 50.60 ASF | Acidity(pH) 4.10 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.3°C | Flatness Fair | 6C2A | | | | | |
| NMR-6D | Start 04-17 | Duty Cycle 50% | Ni Metal 76.87 g/l | Panels 2 Each | 6D1A | None | Ambient | 182,560 | 148,610 | 7.3 4.0 |
| | Finish 04-19 | Pulse On 12.0 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | B | 650°F(24 Hr) | Ambient | 180,605 | 140,885 | 8.7 5.5 |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 31.70 g/l | Mn Comp. 2443 ppm | C | | | 154,085 | 143,734 | 7.0 3.5 |
| | Amp Hrs. 700 | Peak C.D. 50.60 ASF | Acidity(pH) 4.10 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.3°C | Flatness Fair | 6D2A | | | | | |

TABLE II - ELECTROLYTE SPRAY EFFECTS EVALUATION

NASA CONTRACT NAS 8-35817 PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS

| Sample Number | Fabrication Data | Pulse Plating Information | Plating Bath Analytical Data | Deposited Alloy Data | Strip No. | Heat Treatment | Test Temp (°F) | Mechanical Properties (psi) | | | Hardness Rockwell C |
|---------------|------------------|---------------------------|------------------------------|----------------------|-----------|----------------|----------------|-----------------------------|---------|------------|---------------------|
| | | | | | | | | Ultimate | Yield | Elong. (%) | |
| NMR-7A | Start 03-19 | Duty Cycle 40% | Ni Metal 76.84 g/l | Panels 2 Each | 7A1A | None | Ambient | 170,705 | 129,850 | 7.2 | 4.9 |
| | Finish 03-21 | Pulse On 8.0 Msec | Mn Metal 4.6 g/l | Size 4.38"x 8.12" | | | | | | | |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 30.70 g/l | Mn Comp. 1913 ppm | | | | | | | |
| | Amp Hrs. 720 | Peak C.D. 63.25 ASF | Acidity (pH) 3.85 | S Comp. | | | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.6°C | Flatness Fair | | | | | | | |
| NMR-7B | Start 03-24 | Duty Cycle 40% | Ni Metal 76.37 g/l | Panels 2 Each | 7B1A | None | Ambient | 160,095 | 137,675 | 7.5 | 4.4 |
| | Finish 03-26 | Pulse On 8.0 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | | | | | | | |
| | Tank No. E02 | Pulse Off 12.0 Msec | Boric Acid 31.17 g/l | Mn Comp. | | | | | | | |
| | Amp Hrs. 720 | Peak C.D. 63.25 ASF | Acidity (pH) 4.05 | S Comp. | | | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 50.0°C | Flatness Fair | | | | | | | |
| NMR-7C | Start 03-24 | Duty Cycle 40% | Ni Metal 76.37 g/l | Panels 2 Each | 7C1A | None | Ambient | 144,150 | 105,050 | 12.7 | 8.1 |
| | Finish 03-26 | Pulse On 8.0 Msec | Mn Metal 4.4 g/l | Size 4.38"x 8.12" | | | | | | | |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 31.32 g/l | Mn Comp. | | | | | | | |
| | Amp Hrs. 720 | Peak C.D. 63.25 ASF | Acidity (pH) 4.00 | S Comp. | | | | | | | |
| | | Avg. C.D. 25.30 ASF | Temperature 49.4°C | Flatness Fair | | | | | | | |
| NMR-8A | Start 03-21 | Duty Cycle 40% | Ni Metal 76.69 g/l | Panels 2 Each | 8A1A | None | Ambient | 139,485 | 98,780 | 13.3 | 7.7 |
| | Finish 03-24 | Pulse On 8.0 Msec | Mn Metal 4.4 g/l | Size 4.38"x 8.12" | | | | | | | |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 31.32 g/l | Mn Comp. 1288 ppm | | | | | | | |
| | Amp Hrs. 720 | Peak C.D. 50.60 ASF | Acidity (pH) 4.00 | S Comp. | | | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature 49.4°C | Flatness Fair | | | | | | | |
| NMR-8B | Start 03-26 | Duty Cycle 40% | Ni Metal 77.34 g/l | Panels 2 Each | 8B1A | None | Ambient | 125,105 | 96,660 | 13.0 | 7.4 |
| | Finish 03-29 | Pulse On 8.0 Msec | Mn Metal 4.6 g/l | Size 4.38"x 8.12" | | | | | | | |
| | Tank No. E02 | Pulse Off 12.0 Msec | Boric Acid 30.70 g/l | Mn Comp. 1438 ppm | | | | | | | |
| | Amp Hrs. 720 | Peak C.D. 50.60 ASF | Acidity (pH) 4.12 | S Comp. | | | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature 48.8°C | Flatness Fair | | | | | | | |
| NMR-8C | Start 03-31 | Duty Cycle 40% | Ni Metal 78.31 g/l | Panels 2 Each | 8C1A | None | Ambient | 133,520 | 114,790 | 13.0 | 6.6 |
| | Finish 04-03 | Pulse On 8.0 Msec | Mn Metal 4.8 g/l | Size 4.38"x 8.12" | | | | | | | |
| | Tank No. E01 | Pulse Off 12.0 Msec | Boric Acid 31.63 g/l | Mn Comp. | | | | | | | |
| | Amp Hrs. 720 | Peak C.D. 50.60 ASF | Acidity (pH) 4.06 | S Comp. | | | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature 49.4°C | Flatness Fair | | | | | | | |

TABLE III - ELECTROLYTE SPRAY EFFECTS EVALUATION

| NASA CONTRACT NAS 8-35817 PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS | | | | | | | | | | | | | |
|--|---------------------|---------------------------|------------------------------|----------------------|-----------|----------------|----------------|-----------------------------|---------|------------|---|---|---|
| Sample Number | Fabrication Date | Pulse Plating Information | Plating Bath Analytical Data | Deposited Alloy Data | Strip No. | Heat Treatment | Test Temp.(°F) | Mechanical Properties (psi) | | | | | |
| | | | | | | | | Ultimate | Yield | Elong. (%) | | | |
| NMR-9A | Start 03-24 | Duty Cycle 25% | Ni Metal 76.37 g/l | 2 Each | 9A1A | None | Ambient | 185,880 | 141,930 | 5.8 | | | |
| | Finish 03-27 | Pulse On 6.0 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | | | | | | | B | | |
| | Tank No. E01 | Pulse Off 18.0 Msec | Boric Acid 31.47 g/l | Mn Comp. 1758 ppm | | | | | | | | C | |
| | Amp Hrs. 719 | Peak C.D. 80.96 ASF | Acidity (pH) 4.08 | S Comp. ppm | | | | | | | | | D |
| | | Avg. C.D. 20.24 ASF | Temperature 50.0°C | Flatness Fair | | | | | | | | | |
| | Avg. Volts 4.00 | | Thickness .068 in | B | | | | | | | | | |
| | Sprays Double | | to .069 in. | C | | | | | | | | | |
| | | | | D | | | | | | | | | |
| NMR-9B | Start 03-31 | Duty Cycle 25% | Ni Metal 77.66 g/l | 2 Each | 9B1A | None | Ambient | 165,885 | 135,790 | 9.4 | | | |
| | Finish 04-03 | Pulse On 6.0 Msec | Mn Metal 4.6 g/l | Size 4.38"x 8.12" | | | | | | | B | | |
| | Tank No. E02 | Pulse Off 18.0 Msec | Boric Acid 31.78 g/l | Mn Comp. 1716 ppm | | | | | | | | C | |
| | Amp Hrs. 720 | Peak C.D. 80.96 ASF | Acidity (pH) 4.04 | S Comp. ppm | | | | | | | | | D |
| | | Avg. C.D. 20.24 ASF | Temperature 49.2°C | Flatness Fair | | | | | | | | | |
| | Avg. Volts 3.90 | | Thickness .068 in | B | | | | | | | | | |
| | Sprays Double | | to .068 in. | C | | | | | | | | | |
| | | | | D | | | | | | | | | |
| NMR-9C | Start 03-27 | Duty Cycle 25% | Ni Metal 77.34 g/l | 2 Each | 9C1A | None | Ambient | 165,330 | 142,350 | 9.5 | | | |
| | Finish 03-30 | Pulse On 6.0 Msec | Mn Metal 4.8 g/l | Size 4.38"x 8.12" | | | | | | | B | | |
| | Tank No. E01 | Pulse Off 18.0 Msec | Boric Acid 31.32 g/l | Mn Comp. ppm | | | | | | | | C | |
| | Amp Hrs. 720 | Peak C.D. 80.96 ASF | Acidity (pH) 4.11 | S Comp. ppm | | | | | | | | | D |
| | | Avg. C.D. 20.24 ASF | Temperature 49.1°C | Flatness Fair | | | | | | | | | |
| | Avg. Volts 4.10 | | Thickness in | B | | | | | | | | | |
| | Sprays Double | | to | C | | | | | | | | | |
| | | | | D | | | | | | | | | |
| NMR-10A | Start 04-18 | Duty Cycle 50% | Ni Metal 75.92 g/l | 2 Each | 10A1A | None | Ambient | 150,975 | 112,015 | 5.9 | | | |
| | Finish 04-20 | Pulse On 10.0 Msec | Mn Metal 4.8 g/l | Size 4.38"x 8.12" | | | | | | | B | | |
| | Tank No. E02 | Pulse Off 10.0 Msec | Boric Acid 31.01 g/l | Mn Comp. ppm | | | | | | | | C | |
| | Amp Hrs. 600 | Peak C.D. 40.48 ASF | Acidity (pH) 4.07 | S Comp. ppm | | | | | | | | | D |
| | | Avg. C.D. 20.24 ASF | Temperature 49.4°C | Flatness Fair | | | | | | | | | |
| | Avg. Volts 4.02 | | Thickness .060 in | B | | | | | | | | | |
| | Sprays Sing. Square | | to .061 | C | | | | | | | | | |
| | | | | D | | | | | | | | | |
| NMR-10B | Start 04-18 | Duty Cycle 50% | Ni Metal 75.92 g/l | 2 Each | 10B1A | None | Ambient | 150,975 | 112,015 | 5.9 | | | |
| | Finish 04-20 | Pulse On 10.0 Msec | Mn Metal 4.8 g/l | Size 4.38"x 8.12" | | | | | | | B | | |
| | Tank No. E02 | Pulse Off 10.0 Msec | Boric Acid 31.01 g/l | Mn Comp. ppm | | | | | | | | C | |
| | Amp Hrs. 600 | Peak C.D. 40.48 ASF | Acidity (pH) 4.07 | S Comp. ppm | | | | | | | | | D |
| | | Avg. C.D. 20.24 ASF | Temperature 49.4°C | Flatness Fair | | | | | | | | | |
| | Avg. Volts 4.02 | | Thickness .0 in | B | | | | | | | | | |
| | Sprays Sing. Square | | to | C | | | | | | | | | |
| | | | | D | | | | | | | | | |

TABLE IV - ELECTROLYTE SPRAY EFFECTS EVALUATION

| NASA CONTRACT NAS 8-35817 PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS | | | | | | | | | | |
|--|------------------|---------------------------|------------------------------|----------------------|-----------|----------------|---------------|-----------------------------|---------|------------|
| Sample Number | Fabrication Data | Pulse Plating Information | Plating Bath Analytical Data | Deposited Alloy Data | Strip No. | Heat Treatment | Test Temp(°F) | Mechanical Properties (psi) | | |
| | | | | | | | | Ultimate | Yield | Elong. (%) |
| NMR-11A | Start 04-19 | Duty Cycle 40% | Ni Metal 76.55 g/l | Panels 2 Each | 11A1A | None | Ambient | 158,135 | 119,215 | 17.9 12.9 |
| | Finish 04-22 | Pulse On 6.7 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | B | None | Ambient | 169,355 | 127,105 | 14.9 10.7 |
| | Tank No. E01 | Pulse Off 10.0 Msec | Boric Acid 31.78 g/l | Mn Comp. ppm | C | 650°F(24 Hr) | Ambient | 160,055 | 139,700 | 8.0 5.0 |
| | Amp Hrs. 600 | Peak C.D. 50.60 ASF | Acidity(pH) 4.15 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature 49.0°C | Flatness Fair | 11A2A | | | | | |
| | | Avg. Volts 4.00 | | Thickness .057 in | B | | | | | |
| | | Sprays-SingleSquare | | to .058 in. | C | | | | | |
| | | | | | D | | | | | |
| NMR-11B | Start | Duty Cycle 40% | Ni Metal g/l | Panels 2 Each | 11B1A | None | Ambient | 137,110 | 111,555 | 11.6 9.3 |
| | Finish | Pulse On 6.7 Msec | Mn Metal g/l | Size 4.38"x 8.12" | B | None | Ambient | 149,795 | 125,255 | 11.4 8.6 |
| | Tank | Pulse Off 10.0 Msec | Boric Acid g/l | Mn Comp. ppm | C | 650°F(24 Hr) | Ambient | 165,550 | 124,165 | 8.0 5.0 |
| | Amp Hrs. | Peak C.D. 50.60 ASF | Acidity(pH) °C | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | Flatness | 11B2A | | | | | |
| | | Avg. Volts | | Thickness in | B | | | | | |
| | | Sprays- | | to | C | | | | | |
| | | | | | D | | | | | |
| NMR-12A | Start 04-20 | Duty Cycle 50% | Ni Metal 75.29 g/l | Panels 2 Each | 12A1A | None | Ambient | 137,110 | 111,555 | 11.6 9.3 |
| | Finish 04-23 | Pulse On 20.0 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | B | None | Ambient | 149,795 | 125,255 | 11.4 8.6 |
| | Tank No. E02 | Pulse Off 20.0 Msec | Boric Acid 30.55 g/l | Mn Comp. ppm | C | 650°F(24 Hr) | Ambient | 165,550 | 124,165 | 8.0 5.0 |
| | Amp Hrs. 600 | Peak C.D. 40.48 ASF | Acidity(pH) 4.04 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature 49.7°C | Flatness Fair | 12A2A | | | | | |
| | | Avg. Volts 4.00 | | Thickness .060 in | B | | | | | |
| | | Sprays-SingleSquare | | to .061 in. | C | | | | | |
| | | | | | D | | | | | |
| NMR-12B | Start | Duty Cycle 50% | Ni Metal g/l | Panels 2 Each | 12B1A | None | Ambient | 137,110 | 111,555 | 11.6 9.3 |
| | Finish | Pulse On 20.0 Msec | Mn Metal g/l | Size 4.38"x 8.12" | B | None | Ambient | 149,795 | 125,255 | 11.4 8.6 |
| | Tank No. | Pulse Off 20.0 Msec | Boric Acid g/l | Mn Comp. ppm | C | 650°F(24 Hr) | Ambient | 165,550 | 124,165 | 8.0 5.0 |
| | Amp Hrs. | Peak C.D. 40.48 ASF | Acidity(pH) °C | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | Flatness | 12B2A | | | | | |
| | | Avg. Volts | | Thickness in | B | | | | | |
| | | Sprays- | | to | C | | | | | |
| | | | | | D | | | | | |
| NMR-13A | Start 04-22 | Duty Cycle 40% | Ni Metal 78.13 g/l | Panels 2 Each | 13A1A | None | Ambient | 162,715 | 131,340 | 11.5 9.1 |
| | Finish 04-24 | Pulse On 13.4 Msec | Mn Metal 4.7 g/l | Size 4.38"x 8.12" | B | None | Ambient | 182,415 | 137,725 | 11.7 8.9 |
| | Tank No. E01 | Pulse Off 20.0 Msec | Boric Acid 31.47 g/l | Mn Comp. ppm | C | 650°F(24 Hr) | Ambient | 159,575 | 152,925 | 8.0 4.0 |
| | Amp Hrs. 600 | Peak C.D. 50.60 ASF | Acidity(pH) 3.97 | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature 48.9°C | Flatness Fair | 13A2A | | | | | |
| | | Avg. Volts 4.05 | | Thickness .055 in | B | | | | | |
| | | Sprays-SingleSquare | | to .056 in. | C | | | | | |
| | | | | | D | | | | | |
| NMR-13B | Start | Duty Cycle 40% | Ni Metal g/l | Panels 2 Each | 13B1A | None | Ambient | 162,715 | 131,340 | 11.5 9.1 |
| | Finish | Pulse On 13.4 Msec | Mn Metal g/l | Size 4.38"x 8.12" | B | None | Ambient | 182,415 | 137,725 | 11.7 8.9 |
| | Tank No. | Pulse Off 20.0 Msec | Boric Acid g/l | Mn Comp. ppm | C | 650°F(24 Hr) | Ambient | 159,575 | 152,925 | 8.0 4.0 |
| | Amp Hrs. | Peak C.D. 50.60 ASF | Acidity(pH) °C | S Comp. ppm | D | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | Flatness | 13B2A | | | | | |
| | | Avg. Volts | | Thickness in | B | | | | | |
| | | Sprays- | | to | C | | | | | |
| | | | | | D | | | | | |

TABLE V - ELECTROLYTE SPRAY EFFECTS EVALUATION

NASA CONTRACT NAS 8-35817 PHASE I - TASK II NICKEL-MANGANESE OPTIMIZATION PANELS

| Sample Number | Fabrication Data | Pulse Plating Information | Plating Bath Analytical Data | Deposited Alloy Data | Strip No. | Heat Treatment | Test Temp (°F) | Mechanical Properties (psi) | | |
|---------------|------------------|---------------------------|------------------------------|----------------------|-------------------|----------------|----------------|-----------------------------|---------|------------|
| | | | | | | | | Ultimate | Yield | Elong. (%) |
| NMR-14A | Start 04-23 | Duty Cycle | 50% Ni Metal | 74.66 g/l | 2 Each | None | Ambient | 134,340 | 115,660 | 15.7 |
| | Finish 04-25 | Pulse On 30.0 Msec | Mn Metal | 4.6 g/l | Size 4.38"x 8.12" | None | Ambient | 138,095 | 123,840 | 9.2 |
| | Tank No. E02 | Pulse Off 30.0 Msec | Boric Acid | 30.70 g/l | Mn Comp. | None | Ambient | 135,915 | 126,400 | 3.0* |
| | Amp Hrs. 600 | Peak C.D. 40.48 ASF | Acidity (pH) | 3.99 | S Comp. | 650°F (24 Hr) | Ambient | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | 49.7°C | Flatness | | | | | |
| | | Avg. Volts 4.02 | | Thickness .056 in | 14A2A | | | | | |
| | | Sprays-SingleSquare | | to .057 in. | C | | | | | |
| NMR-14B | Start | Duty Cycle | 50% Ni Metal | g/l | 2 Each | None | Ambient | 171,520 | 129,070 | 4.2 |
| | Finish | Pulse On 30.0 Msec | Mn Metal | g/l | Size 4.38"x 8.12" | None | Ambient | 184,505 | 156,540 | 3.0* |
| | Tank No. | Pulse Off 30.0 Msec | Boric Acid | g/l | Mn Comp. | 650°F (24 Hr) | Ambient | | | |
| | Amp Hrs. | Peak C.D. 40.48 ASF | Acidity (pH) | 3.94 | S Comp. | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | 48.8°C | Flatness | | | | | |
| | | Avg. Volts 4.02 | | Thickness .056 in | 14B2A | | | | | |
| | | Sprays-SingleSquare | | to .057 in. | B | | | | | |
| | | | | | C | | | | | |
| | | | | | D | | | | | |
| NMR-15A | Start 04-25 | Duty Cycle | 40% Ni Metal | 78.07 g/l | 2 Each | None | Ambient | 171,520 | 129,070 | 4.2 |
| | Finish 04-27 | Pulse On 20.0 Msec | Mn Metal | 4.6 g/l | Size 4.38"x 8.12" | None | Ambient | 184,505 | 156,540 | 3.0* |
| | Tank No. E01 | Pulse Off 30.0 Msec | Boric Acid | 30.70 g/l | Mn Comp. | 650°F (24 Hr) | Ambient | | | |
| | Amp Hrs. 600 | Peak C.D. 50.60 ASF | Acidity (pH) | 3.94 | S Comp. | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | 48.8°C | Flatness | | | | | |
| | | Avg. Volts 4.02 | | Thickness .056 in | 15A2A | | | | | |
| | | Sprays-SingleSquare | | to .057 in. | B | | | | | |
| | | | | | C | | | | | |
| | | | | | D | | | | | |
| NMR-15B | Start | Duty Cycle | 40% Ni Metal | g/l | 2 Each | None | Ambient | 171,520 | 129,070 | 4.2 |
| | Finish | Pulse On 20.0 Msec | Mn Metal | g/l | Size 4.38"x 8.12" | None | Ambient | 184,505 | 156,540 | 3.0* |
| | Tank No. | Pulse Off 30.0 Msec | Boric Acid | g/l | Mn Comp. | 650°F (24 Hr) | Ambient | | | |
| | Amp Hrs. | Peak C.D. 50.60 ASF | Acidity (pH) | 4.02 | S Comp. | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | 49.4°C | Flatness | | | | | |
| | | Avg. Volts 4.02 | | Thickness .059 in | 15B2A | | | | | |
| | | Sprays-SingleSquare | | to .060 in. | B | | | | | |
| | | | | | C | | | | | |
| | | | | | D | | | | | |
| NMR-16A | Start 04-25 | Duty Cycle | 33.3% Ni Metal | 75.84 g/l | 2 Each | None | Ambient | 144,535 | 111,670 | 2.3 |
| | Finish 04-28 | Pulse On 5.0 Msec | Mn Metal | 4.5 g/l | Size 4.38"x 8.12" | None | Ambient | 133,250 | 111,045 | 10.0 |
| | Tank No. E02 | Pulse Off 10.0 Msec | Boric Acid | 30.40 g/l | Mn Comp. | 650°F (24 Hr) | Ambient | | | |
| | Amp Hrs. 600 | Peak C.D. 60.72 ASF | Acidity (pH) | 4.02 | S Comp. | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | 49.4°C | Flatness | | | | | |
| | | Avg. Volts 4.02 | | Thickness .059 in | 16A2A | | | | | |
| | | Sprays-SingleSquare | | to .060 in. | B | | | | | |
| | | | | | C | | | | | |
| | | | | | D | | | | | |
| NMR-16B | Start | Duty Cycle | 33.3% Ni Metal | g/l | 2 Each | None | Ambient | 144,535 | 111,670 | 2.3 |
| | Finish | Pulse On 5.0 Msec | Mn Metal | g/l | Size 4.38"x 8.12" | None | Ambient | 133,250 | 111,045 | 10.0 |
| | Tank No. | Pulse Off 10.0 Msec | Boric Acid | g/l | Mn Comp. | 650°F (24 Hr) | Ambient | | | |
| | Amp Hrs. | Peak C.D. 60.72 ASF | Acidity (pH) | 4.02 | S Comp. | | | | | |
| | | Avg. C.D. 20.24 ASF | Temperature | 49.4°C | Flatness | | | | | |
| | | Avg. Volts 4.02 | | Thickness .059 in | 16B2A | | | | | |
| | | Sprays-SingleSquare | | to .060 in. | B | | | | | |
| | | | | | C | | | | | |
| | | | | | D | | | | | |

C. Task I - Heat Treatment of Alloy Structural Shell (Phase B)

For reason of simplifying the alloy optimization effort and the fact that heat treatment of the alloy for best combination of strength and ductility is necessary, the planned work in this task is being reported under Phase A, Task II.

D. Task II - Tooling for EF of Prototype SSME - MCC (Phase B)

The subscale MCC mandrel machining was completed as scheduled. The mandrel is a two-piece design to facilitate separation of the electroformed shroud configuration specimens. Each section has been zincated for bonding and flash chromium plated to protect the surfaces from corrosion and scratching. We expect to use this mandrel for many electroforming trials.

E. Task III - Prototype MCC Preparation for Electroforming (Phase B)

The mandrel electroforming strongback and MCC rotating drive system are being integrated. Plexiglass shield support soft-tooling is in fabrication. Special provision is being made for a separate drive to rotate the upper shield support in a counter direction to the mandrel. This will enable the use of conformal rotating blades to provide additional electrolyte shear at the surface being electroformed. This will augment forced sprays to promote higher manganese concentrations in the alloy. We anticipate this may be required due to the fact that the mandrel is a complex shaped rotating mandrel which will be under continuous deposition over all areas regardless of whether these areas are "seeing" a strong diffusion layer shearing action, or not. By being able to independently drive a "squirrel cage" of conformal blades, it should be possible to provide high turbulence over a greater area of the mandrel.

Our plans for Phase B electroforming on the mandrel call for evaluation of alloy chemistry and hardness variability based on mandrel rotational speeds and multiple spray placement. If manganese content is not sufficient to promote proper hardness and retention of good hardness after heat treating, we expect to correct this condition by one or more of the following actions:

1. Increase the pulse off time for better manganese diffusion to the cathode surface.
2. Increase the manganese content in the electrolyte. This can only be done as long as residual stress is not prohibitive.
3. Increase spray agitation capacity.
4. Increase average current density for pulse plating.

Based on the magnitude of samples required for evaluation when we start electroforming MCC configurations, it is unlikely that novel agitation systems such as the counter rotating blades, it is recommended that such evaluations be considered in follow-on work - should continuation of the alloy electroforming program be considered appropriate.

III. CURRENT PROBLEMS

The previous discussions of this progress report have shown that

electrolyte agitation variations have more pronounced effects on mechanical properties than had been anticipated. Conditions which lead to specific mechanical properties on simple flat shapes will require modification when applied to cylindrical and conical shapes such as the MCC. Although corrective actions to solve this problem are generally defined, achieving desired mechanical properties and uniform alloy composition on complex configurations is now expected to consume more study than originally anticipated. We expect the Phase A work will provide an optimum alloy for mechanical properties at the expected MCC service temperatures; however, duplicating these properties on a complex round shape may require extending some efforts beyond the schedule and funding of the present contract.

IV. WORK PLANNED

1. Complete electrolyte agitation evaluation with respect to mechanical properties and manganese contents of alloys.
2. Select specimens for continued study with respect to effects of various heat treatments on ambient and elevated temperature properties.
3. Continue soft tooling for subscale mandrel - shield support, rotational drive connections, etc.

V. FINANCIAL DATA

See attached NASA Form 533P.

NATIONAL / AERONAUTICS AND SPACE ADMINISTRATION
MONTHLY CONTRACTOR FINANCIAL MANAGEMENT PERFORMANCE ANALYSIS REPORT

Form Approved
 Budget Bureau No. 104-R0011

2. REPORT FOR PERIOD ENDING AND NUMBER OF
 OPERATING DAYS
 April 26, 1985 (19 Operating Days)

TO: PROCUREMENT OFFICE
 GEORGE C. MARSHALL SPACE FLIGHT CENTER
 MARSHALL SPACE FLIGHT CENTER, ALABAMA 35812

FROM: NIAGARA FRONTIER OPERATIONS
 BELL AEROSPACE TEXTRON
 POST OFFICE BOX ONE, BUFFALO, NY 14240

1. DESCRIPTION
 OF
 CONTRACT

8. TYPE

Cost-Plus-Fixed-Fee
 Study of High Performance Alloy
 Electroforming

3. CONTRACT NO. AND LATEST DEFINITIVE AMENDMENT NO.

NAS 8-35817 Modification No. 3

4. AUTH. CONTR. REP. (Signature)

DATE
 May 8, 1985

11. TECHNICAL ASSESSMENT OF PROGRESS

5. SCHEDULE AND STATUS

| 6. REPORTING CATEGORY | 7. PLANNED VALUE OF WORK | | 8. ACTUAL COSTS/HOURS | 9. VARIANCE | | 10. CONTRACTOR'S ESTIMATED FINAL COST | 1984 | | | | | | | | | | | | 1985 | | | | | | | | | | | | N. TECH N. COM- PLETED | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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